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(54) **CARRIER SENSE MULTIPLE ACCESS (CSMA) PROTOCOLS FOR POWER LINE COMMUNICATIONS (PLC)**

(52) **U.S. Cl.**
CPC **H04L 12/413** (2013.01); **H04B 3/544** (2013.01); **H04L 5/0096** (2013.01)

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(56) **References Cited**

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U.S. PATENT DOCUMENTS

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7,313,113 B1 12/2007 Hills et al.
7,352,770 B1 4/2008 Yonge, III et al.
7,545,781 B2 6/2009 Otsuki et al.
(Continued)

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(57) **ABSTRACT**

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Systems and methods for carrier sense multiple access (CSMA) protocols for power line communications (PLC) are described. In some embodiments, a method may include performing a virtual carrier sensing operation and, in response to the virtual carrier sensing operation indicating that a communication channel is idle, calculating a contention window. The method may also include performing a physical carrier sensing operation subsequent to the virtual carrier sensing operation, the physical carrier sensing operation based, at least in part, upon the contention window. In response to the physical carrier sensing operation indicating that the communication channel is idle, the method may then include transmitting data over the channel. In other embodiments, another method may include determining that a data transmission is a unicast transmission and that an acknowledgement message has not been received. The method may further include incrementing a backoff parameter and repeating one or more carrier sense operations.

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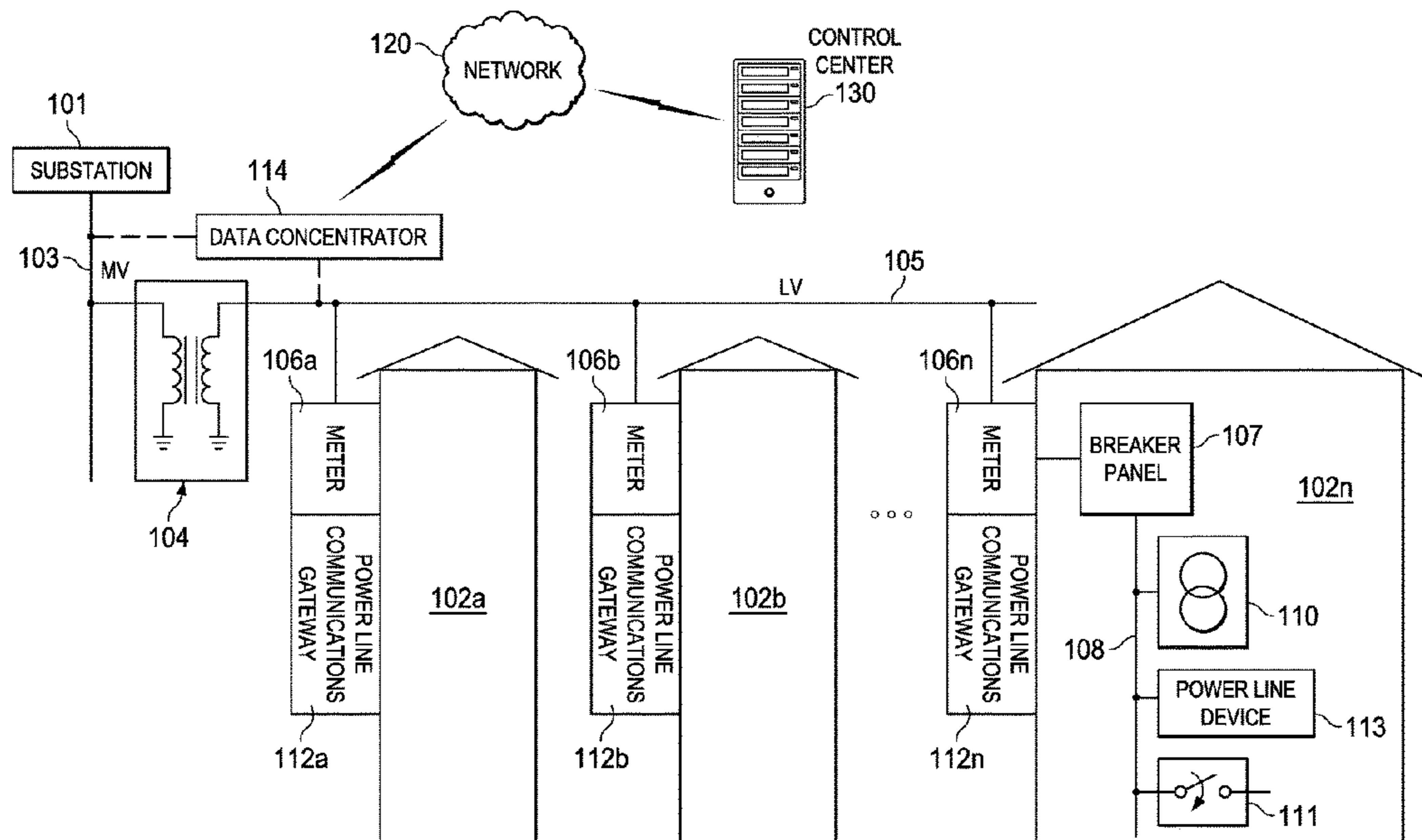
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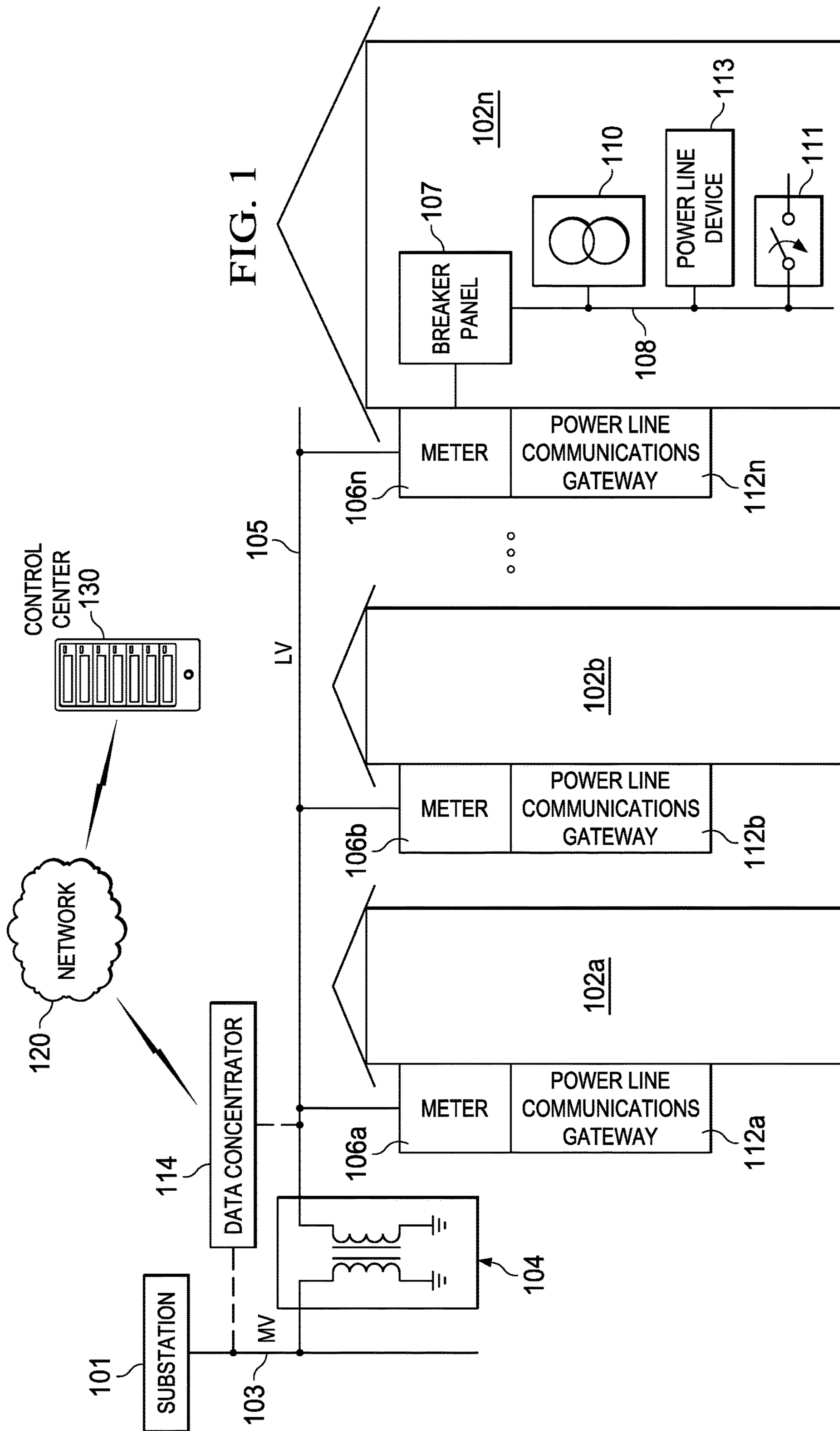
- (60) Provisional application No. 61/424,159, filed on Dec. 17, 2010.

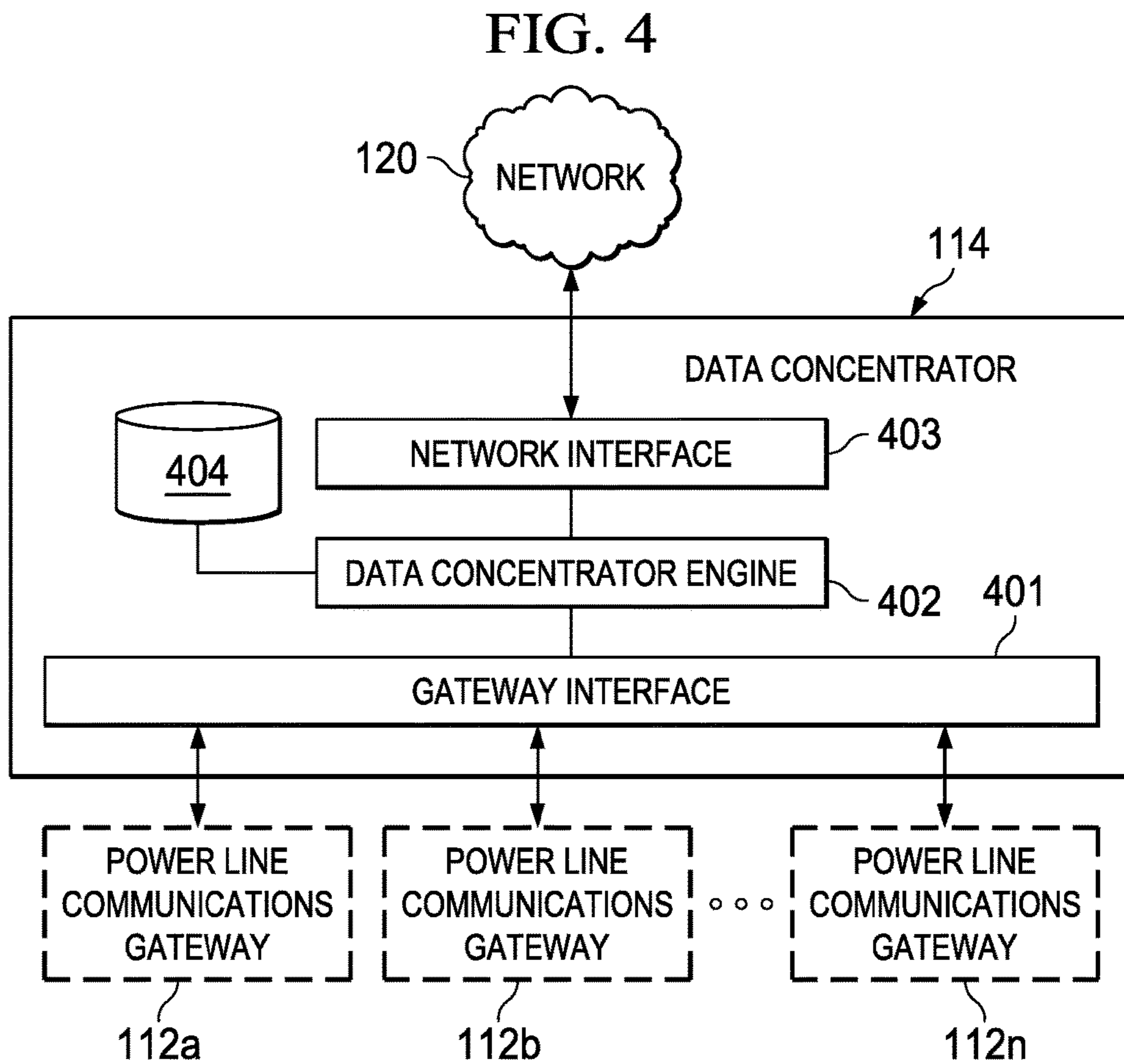
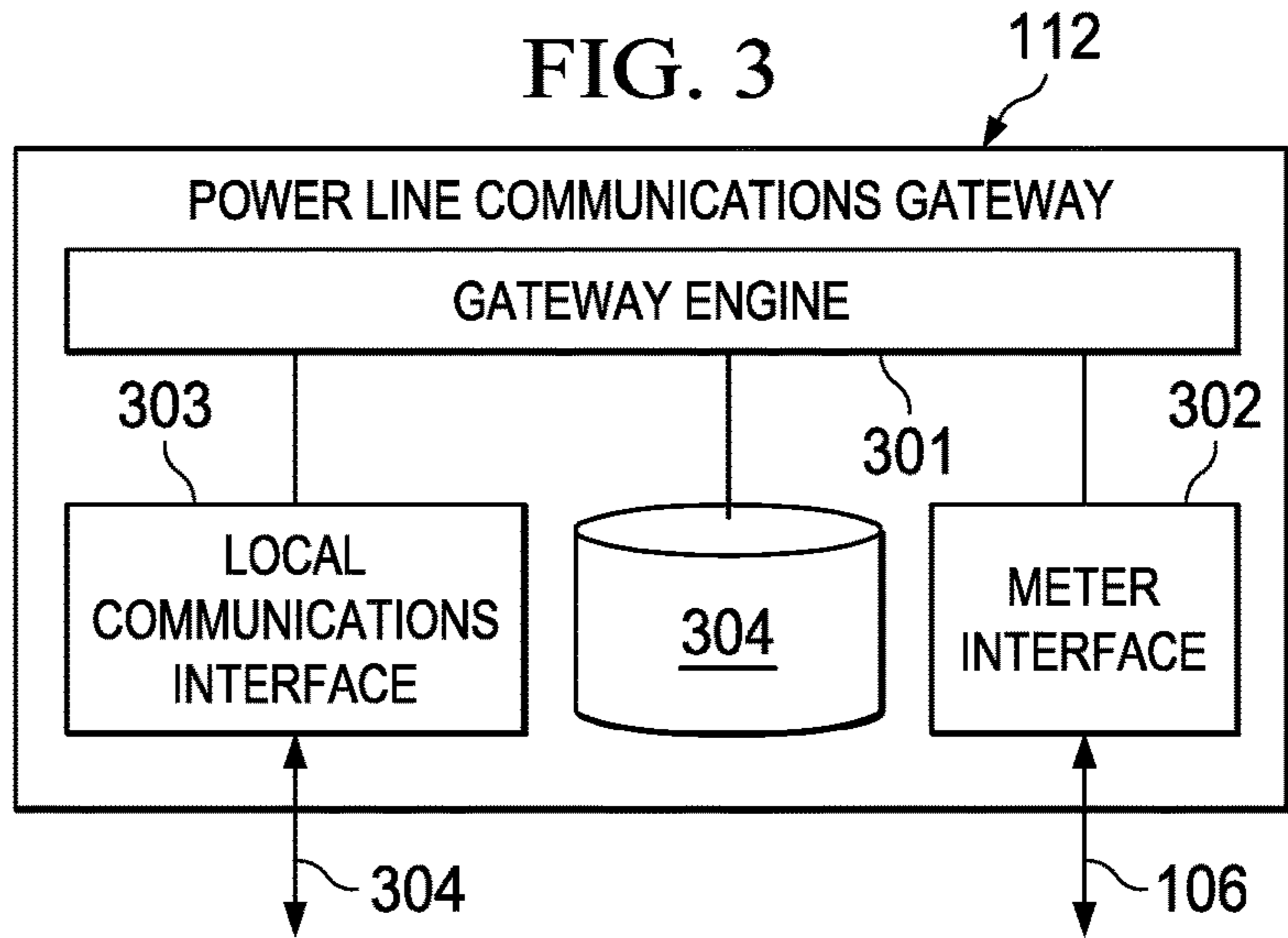
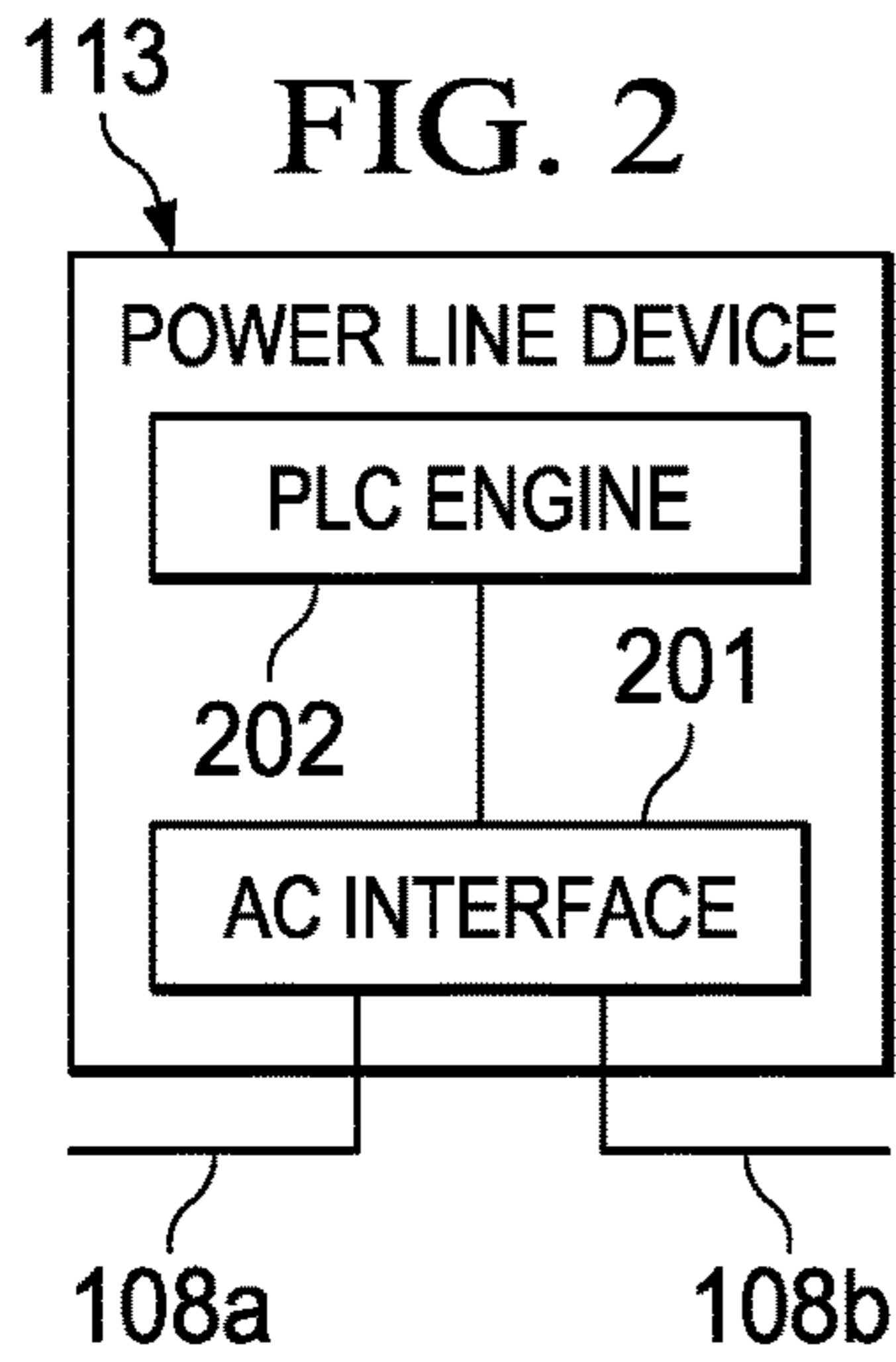
(56) **References Cited**

U.S. PATENT DOCUMENTS

7,570,656	B2	8/2009	Raphaeli et al.	
8,711,873	B2	4/2014	Du et al.	
9,094,234	B2	7/2015	Du et al.	
2003/0103521	A1*	6/2003	Raphaeli	H04B 3/542 370/445
2005/0025176	A1*	2/2005	Ko	H04W 74/085 370/448
2005/0141547	A1*	6/2005	Cho	H04W 74/0875 370/448
2006/0084444	A1*	4/2006	Kossi	H04W 84/18 455/450
2007/0230497	A1	10/2007	Choi et al.	
2009/0129353	A1	5/2009	Ki et al.	
2009/0252053	A1*	10/2009	Leith	H04W 24/10 370/252
2010/0202471	A1	8/2010	Maki	
2011/0085442	A1*	4/2011	Lin	H04L 45/42 370/235
2011/0149723	A1*	6/2011	Gong	H04L 1/0002 370/216
2012/0008626	A1*	1/2012	Brederveld	G06Q 10/087 370/392

* cited by examiner





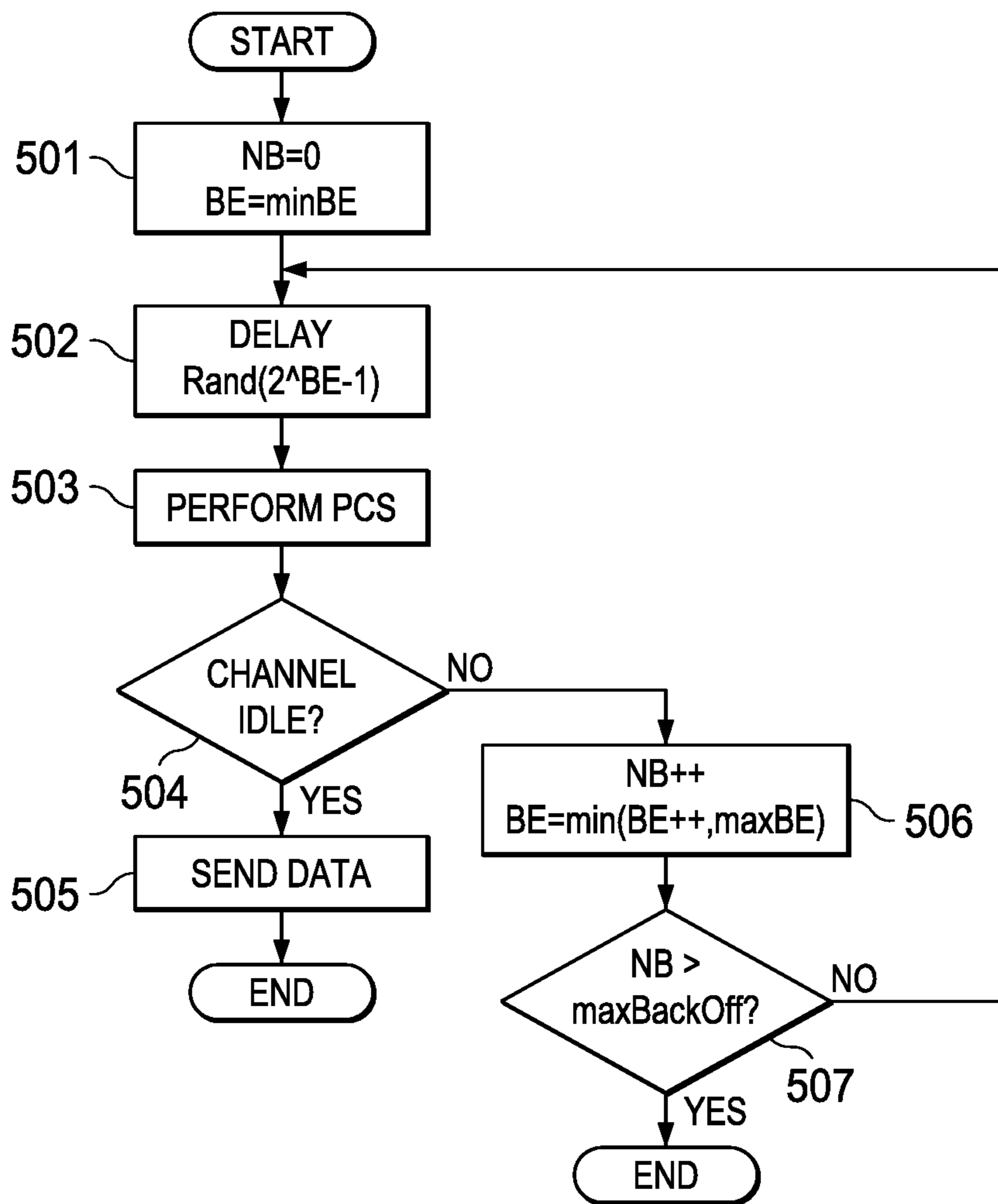


FIG. 5
(PRIOR ART)

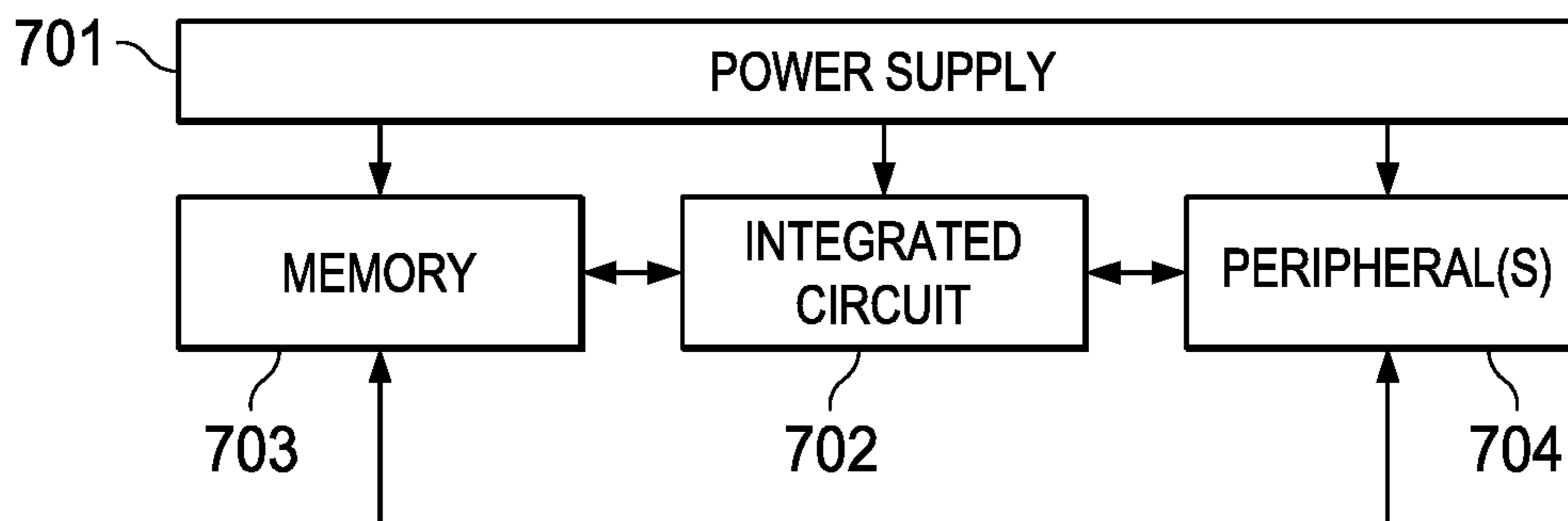


FIG. 7

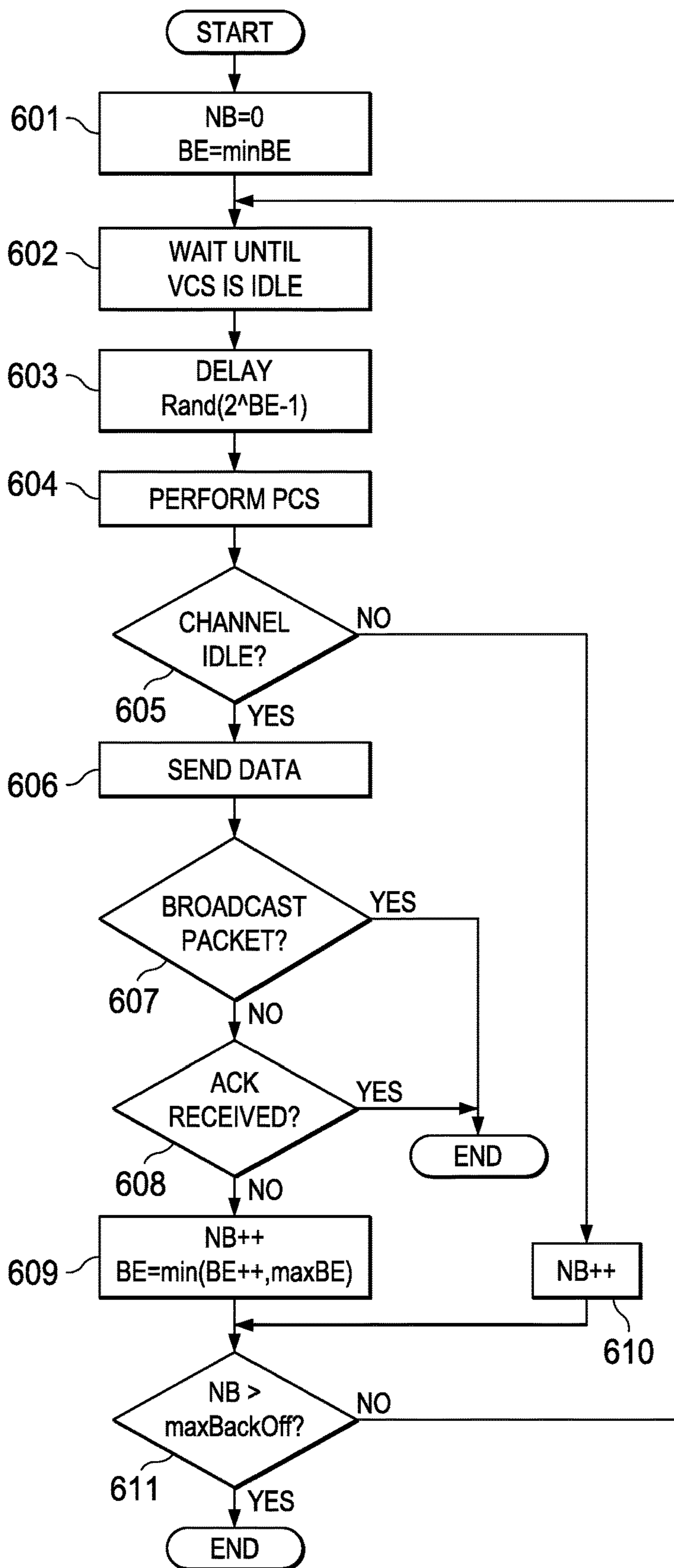


FIG. 6

**CARRIER SENSE MULTIPLE ACCESS
(CSMA) PROTOCOLS FOR POWER LINE
COMMUNICATIONS (PLC)**

CROSS-REFERENCE TO RELATED
APPLICATION(S)

This application is a continuation of U.S. patent application Ser. No. 14/744,295, filed Jun. 19, 2015, which is a continuation of U.S. patent application Ser. No. 14/264,676, filed Apr. 29, 2014, now U.S. Pat. No. 9,094,234, granted Jul. 28, 2015, which is a continuation of U.S. patent application Ser. No. 13/300,812, filed Nov. 21, 2011, now U.S. Pat. No. 8,711,873, granted Apr. 29, 2014, which also claims the benefit of the filing date of U.S. Provisional Patent Application No. 61/424,159, which is entitled "CSMA Method for Advanced Metering Infrastructure Networks" and was filed on Dec. 17, 2010, the disclosure of each application is hereby incorporated by reference herein in its entirety.

TECHNICAL FIELD

Embodiments are directed, in general, to power line communications (PLC), and, more specifically, to carrier sense multiple access (CSMA) protocols for PLC.

BACKGROUND

Power line communications (PLC) include systems for communicating data over the same medium (i.e., a wire or conductor) that is also used to transmit electric power to residences, buildings, and other premises. Once deployed, PLC systems may enable a wide array of applications, including, for example, automatic meter reading and load control (i.e., utility-type applications), automotive uses (e.g., charging electric cars), home automation (e.g., controlling appliances, lights, etc.), and/or computer networking (e.g., Internet access), to name only a few.

Various PLC standardizing efforts are currently being undertaken around the world, each with its own unique characteristics. Generally speaking, PLC systems may be implemented differently depending upon local regulations, characteristics of local power grids, etc. Examples of competing PLC standards include the IEEE 1901, HomePlug AV, Powerline Intelligent Metering Evolution (PRIME), and the ITU-T G.hn (e.g., G.9960 and G.9961) specifications.

SUMMARY

Systems and methods for implementing carrier sense multiple access (CSMA) protocols in power line communications (PLC) are described. In an illustrative embodiment, a method may include performing a virtual carrier sensing operation and, in response to the virtual carrier sensing operation indicating that a communication channel is idle, calculating a contention window. The method may also include performing a physical carrier sensing operation subsequent to the virtual carrier sensing operation, the physical carrier sensing operation based, at least in part, upon the contention window. Then, in response to the physical carrier sensing operation indicating that the communication channel is idle, the method may include transmitting data over the channel.

In some cases, for example, calculating the contention window may include setting a length of the contention window, and the physical carrier sensing operation may be

carried out at a randomly selected time within the contention window. Also, the method may include repeating the virtual carrier sensing operation until it indicates that the communication channel is idle.

5 Additionally or alternatively, the method may include, in response to the physical carrier sensing operation indicating that the communication channel is not idle, repeating the virtual carrier sensing operation until it indicates that the communication channel is idle and increasing the length of the contention window to create a modified contention window. For instance, increasing the length of the contention window may include increasing the length of the contention window by an amount corresponding to a number of previous attempts to transmit the data. The method may also include performing a second physical carrier sensing operation subsequent to the repeated virtual carrier sensing operation, the second physical carrier sensing operation based, at least in part, upon the modified contention window. For example, the second physical carrier sensing operation may be carried out at a randomly selected time within the modified contention window. The method may further include, in response to the second physical carrier sensing operation indicating that the communication channel is idle, transmitting data over the communication channel.

20 In another illustrative embodiment, a method may include: (a) in response to a virtual carrier sense operation indicating that an access channel is free, performing a physical carrier sensing operation based, at least in part, upon an original time window; (b) in response to the physical carrier sensing operation indicating that the access channel is free, initiating a data transmission over the access channel; (c) in response to the data transmission being a unicast transmission and an acknowledgment message not being received by the PLC device, incrementing a backoff counter and increasing the original time window; and (d) in response to the backoff counter having a value smaller than a maximum number of allowed backoff operations, repeating at least (a) and (b) using the increased time window.

30 In some implementations, increasing the original time window may include increasing a length of the original time window. Also, the physical carrier sensing operation may be performed at a randomly selected time within the original time window, and the repeated physical carrier sensing operation may be performed at a randomly selected time within the incremented time window.

40 Furthermore, the method may include monitoring an output of the virtual carrier sensing operation until it indicates that the access channel is free. Additionally or alternatively, the method may include, in response to the physical carrier sensing operation indicating that the access channel is busy, increasing the backoff counter, maintaining the original time window, and performing a second physical carrier sensing operation subsequent to a second virtual carrier sensing operation, the second physical carrier sensing operation based, at least in part, upon the original time window. For example, the second physical carrier sensing operation may be carried out at a randomly selected time within the original time window. The method may also include in response to the second physical carrier sensing operation indicating that the access channel is free, transmitting data over the access channel.

50 In yet another illustrative embodiment, the method may include transmitting data at a time selected within a contention window in response to a determination by a carrier sense operation that a channel is available. The method may also include determining that the data transmission is a unicast transmission, determining that an acknowledgement

message has not been received, and increasing the contention window. The method may further include re-transmitting the data at a time selected within the increased contention window.

The method may also include re-transmitting the data in response to another determination by a repeated carrier sense operation that the channel is available. In various implementations, the carrier sense operation may be a virtual carrier sense operation, a physical carrier sense operation, or a combination of physical and virtual carrier sense operations.

In some embodiments, one or more of the methods described herein may be performed by one or more PLC devices (e.g., a PLC modem, etc.). In other embodiments, a tangible electronic storage medium may have program instructions stored thereon that, upon execution by a processor within one or more PLC devices, cause the one or more PLC devices to perform one or more operations disclosed herein. Examples of such a processor include, but are not limited to, a digital signal processor (DSP), an application specific integrated circuit (ASIC), a system-on-chip (SoC) circuit, a field-programmable gate array (FPGA), a microprocessor, or a microcontroller. In yet other embodiments, a PLC device may include at least one processor and a memory coupled to the at least one processor, the memory configured to store program instructions executable by the at least one processor to cause the PLC device to perform one or more operations disclosed herein.

BRIEF DESCRIPTION OF THE DRAWINGS

Having thus described the invention(s) in general terms, reference will now be made to the accompanying drawings, wherein:

FIG. 1 is a diagram of a PLC system according to some embodiments.

FIG. 2 is a block diagram of a PLC device or modem according to some embodiments.

FIG. 3 is a block diagram of a PLC gateway according to some embodiments.

FIG. 4 is a block diagram of a PLC data concentrator according to some embodiments.

FIG. 5 is a flowchart of a prior art CSMA technique.

FIG. 6 is a flowchart of a CSMA technique according to some embodiments.

FIG. 7 is a block diagram of an integrated circuit according to some embodiments.

DETAILED DESCRIPTION

The invention(s) now will be described more fully hereinafter with reference to the accompanying drawings. The invention(s) may, however, be embodied in many different forms and should not be construed as limited to the embodiments set forth herein. Rather, these embodiments are provided so that this disclosure will be thorough and complete, and will fully convey the scope of the invention(s) to a person of ordinary skill in the art. A person of ordinary skill in the art may be able to use the various embodiments of the invention(s).

Turning to FIG. 1, a power line communication (PLC) system is depicted according to some embodiments. Medium voltage (MV) power lines **103** from substation **101** typically carry voltage in the tens of kilovolts range. Transformer **104** steps the MV power down to low voltage (LV) power on LV lines **105**, carrying voltage in the range of 100-240 VAC. Transformer **104** is typically designed to

operate at very low frequencies in the range of 50-60 Hz. Transformer **104** does not typically allow high frequencies, such as signals greater than 100 KHz, to pass between LV lines **105** and MV lines **103**. LV lines **105** feed power to customers via meters **106a-n**, which are typically mounted on the outside of residences **102a-n**. (Although referred to as “residences,” premises **102a-n** may include any type of building, facility or location where electric power is received and/or consumed.) A breaker panel, such as panel **107**, provides an interface between meter **106n** and electrical wires **108** within residence **102n**. Electrical wires **108** deliver power to outlets **110**, switches **111** and other electric devices within residence **102n**.

The power line topology illustrated in FIG. 1 may be used to deliver high-speed communications to residences **102a-n**. In some implementations, power line communications modems or gateways **112a-n** may be coupled to LV power lines **105** at meter **106a-n**. PLC modems/gateways **112a-n** may be used to transmit and receive data signals over MV/LV lines **103/105**. Such data signals may be used to support metering and power delivery applications (e.g., smart grid applications), communication systems, high speed Internet, telephony, video conferencing, and video delivery, to name a few. By transporting telecommunications and/or data signals over a power transmission network, there is no need to install new cabling to each subscriber **102a-n**. Thus, by using existing electricity distribution systems to carry data signals, significant cost savings are possible.

An illustrative method for transmitting data over power lines may use a carrier signal having a frequency different from that of the power signal. The carrier signal may be modulated by the data, for example, using an orthogonal frequency division multiplexing (OFDM) scheme or the like.

PLC modems or gateways **112a-n** at residences **102a-n** use the MV/LV power grid to carry data signals to and from PLC data concentrator **114** without requiring additional wiring. Concentrator **114** may be coupled to either MV line **103** or LV line **105**. Modems or gateways **112a-n** may support applications such as high-speed broadband Internet links, narrowband control applications, low bandwidth data collection applications, or the like. In a home environment, for example, modems or gateways **112a-n** may further enable home and building automation in heat and air conditioning, lighting, and security. Also, PLC modems or gateways **112a-n** may enable AC or DC charging of electric vehicles and other appliances. An example of an AC or DC charger is illustrated as PLC device **113**. Outside the premises, power line communication networks may provide street lighting control and remote power meter data collection.

One or more concentrators **114** may be coupled to control center **130** (e.g., a utility company) via network **120**. Network **120** may include, for example, an IP-based network, the Internet, a cellular network, a WiFi network, a WiMax network, or the like. As such, control center **130** may be configured to collect power consumption and other types of relevant information from gateway(s) **112** and/or device(s) **113** through concentrator(s) **114**. Additionally or alternatively, control center **130** may be configured to implement smart grid policies and other regulatory or commercial rules by communicating such rules to each gateway(s) **112** and/or device(s) **113** through concentrator(s) **114**.

FIG. 2 is a block diagram of PLC device **113** according to some embodiments. As illustrated, AC interface **201** may be coupled to electrical wires **108a** and **108b** inside of premises **112n** in a manner that allows PLC device **113** to switch the connection between wires **108a** and **108b** off using a switch-

ing circuit or the like. In other embodiments, however, AC interface 201 may be connected to a single wire 108 (i.e., without breaking wire 108 into wires 108a and 108b) and without providing such switching capabilities. In operation, AC interface 201 may allow PLC engine 202 to receive and transmit PLC signals over wires 108a-b. In some cases, PLC device 113 may be a PLC modem. Additionally or alternatively, PLC device 113 may be a part of a smart grid device (e.g., an AC or DC charger, a meter, etc.), an appliance, or a control module for other electrical elements located inside or outside of premises 112n (e.g., street lighting, etc.).

PLC engine 202 may be configured to transmit and/or receive PLC signals over wires 108a and/or 108b via AC interface 201 using a particular frequency band. In some embodiments, PLC engine 202 may be configured to transmit OFDM signals, although other types of modulation schemes may be used. As such, PLC engine 202 may include or otherwise be configured to communicate with metrology or monitoring circuits (not shown) that are in turn configured to measure power consumption characteristics of certain devices or appliances via wires 108, 108a, and/or 108b. PLC engine 202 may receive such power consumption information, encode it as one or more PLC signals, and transmit it over wires 108, 108a, and/or 108b to higher-level PLC devices (e.g., PLC gateways 112n, data aggregators 114, etc.) for further processing. Conversely, PLC engine 202 may receive instructions and/or other information from such higher-level PLC devices encoded in PLC signals, for example, to allow PLC engine 202 to select a particular frequency band in which to operate.

FIG. 3 is a block diagram of PLC gateway 112 according to some embodiments. As illustrated in this example, gateway engine 301 is coupled to meter interface 302, local communication interface 304, and frequency band usage database 304. Meter interface 302 is coupled to meter 106, and local communication interface 304 is coupled to one or more of a variety of PLC devices such as, for example, PLC device 113. Local communication interface 304 may provide a variety of communication protocols such as, for example, ZIGBEE, BLUETOOTH, WI-FI, WI-MAX, ETHERNET, etc., which may enable gateway 112 to communicate with a wide variety of different devices and appliances. In operation, gateway engine 301 may be configured to collect communications from PLC device 113 and/or other devices, as well as meter 106, and serve as an interface between these various devices and PLC data concentrator 114. Gateway engine 301 may also be configured to allocate frequency bands to specific devices and/or to provide information to such devices that enable them to self-assign their own operating frequencies.

In some embodiments, PLC gateway 112 may be disposed within or near premises 102n and serve as a gateway to all PLC communications to and/or from premises 102n. In other embodiments, however, PLC gateway 112 may be absent and PLC devices 113 (as well as meter 106n and/or other appliances) may communicate directly with PLC data concentrator 114. When PLC gateway 112 is present, it may include database 304 with records of frequency bands currently used, for example, by various PLC devices 113 within premises 102n. An example of such a record may include, for instance, device identification information (e.g., serial number, device ID, etc.), application profile, device class, and/or currently allocated frequency band. As such, gateway engine 301 may use database 304 in assigning, allocating, or otherwise managing frequency bands assigned to its various PLC devices.

FIG. 4 is a block diagram of a PLC data concentrator according to some embodiments. Gateway interface 401 is coupled to data concentrator engine 402 and may be configured to communicate with one or more PLC gateways 112a-n. Network interface 403 is also coupled to data concentrator engine 402 and may be configured to communicate with network 120. In operation, data concentrator engine 402 may be used to collect information and data from multiple gateways 112a-n before forwarding the data to control center 130. In cases where PLC gateways 112a-n are absent, gateway interface 401 may be replaced with a meter and/or device interface (now shown) configured to communicate directly with meters 116a-n, PLC devices 113, and/or other appliances. Further, if PLC gateways 112a-n are absent, frequency usage database 404 may be configured to store records similar to those described above with respect to database 304.

Generally speaking, prior to transmitting a signal across power lines or wires 103, 105, and/or 108, a PLC device may attempt to detect whether a given communication or access channel (e.g., frequency band) is currently in use. Channel access may be accomplished, for example, by using the Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA) mechanism with a random backoff time. The random backoff mechanism may spread the time over which PLC devices attempt to transmit, thereby reducing the probability of collision. In other words, each time a device wishes to transmit data frames, it may wait for a random period. If the channel is found to be idle or free, following the random backoff, the device may transmit its data. If the channel is found to be busy, following the random backoff, the device may wait for another random period before trying to access the channel again.

In various embodiments, different CSMA techniques may be employed. For instance, physical carrier sense (PCS) may be provided by a physical layer (PHY) upon detection of a preamble. In contrast, a virtual carrier sense (VCS) mechanism may be provided by a media access control (MAC) layer by tracking the expected duration of channel occupancy. Virtual carrier sense may be set, for example, by the length of received packet (or upon collision). In these cases, VCS tracks or estimates the expected duration of the “busy” state of the medium (i.e., when a given PLC device is transmitting data over power lines or wires 103, 105, and/or 108).

FIG. 5 shows a flowchart of a prior art CSMA method that may be applicable, for instance, to a non-beacon personal area network (PAN) as described in the IEEE 802.15.4 standard. Using this method, a random backoff mechanism spreads the time over which stations attempt to transmit (thereby reducing the probability of collision). This CSMA algorithm is typically used before the transmission of data or MAC command frames, and it is implemented using units of time called “backoff periods,” where one backoff period is equal to unitBackoffPeriod symbols.

As illustrated in block 501, each device may maintain two variables for each transmission attempt: NB and BE. Specifically, NB is the number of times the CSMA algorithm was required to backoff while attempting the current transmission, which may be initialized to “0” before each new transmission attempt. On the other hand, BE is the backoff exponent, which is related to how many backoff periods a device shall wait before attempting to assess a channel and which may be initialized to the value of minBE. The method may initialize NB and BE and then proceed to block 502. At block 502, the method may create a delay, for a random number of complete backoff periods (e.g., in the range 0 to

$2^{BE}-1$), and then request that a PCS operation be performed in block **503**. The backoff time may then be given by $\text{Backoff Time} = \text{Random}(2^{BE}-1) \times \text{aSlotTime}$; where aSlotTime is equal to the duration of a contention window slot (e.g., by number of symbols).

At block **504**, if the channel is assessed to be busy, the method may increment both NB and BE by one in block **506**, while ensuring that BE does not exceed maxBE (for high priority packets, maxBE may be equal to minBE). At block **507**, if the value of NB is less than or equal to maxCSMABackoffs, the method may return to block **502**. If the value of NB is greater than maxCSMABackoffs, the method shall terminate, for example, with a channel access failure status or indication. Returning to block **504**, if the channel is assessed to be idle, the method may immediately begin transmission of the frame at block **505**.

As the inventors hereof have recognized with respect to the method described in FIG. **5**, however, PCS is sensed prematurely. Each PCS interval is calculated independently of a VCS sensing result. If one node is sending a large packet, the competing node may fail easily due to unnecessary PCS trials. Additionally or alternatively, contention window increases prematurely. Every time PCS is busy, the BE is increased. Thus, if a node fails the first time of PCS, it then has a higher chance than the others to fail the following PCS due to its increased window, creating unfairness problems.

To address these and other issues, embodiments discussed herein provide techniques for using one or more VCS operations to save one or more unnecessary PCS operations. Also, in some implementations, the contention window may be increased when an ACK message or package is lost, thus differentiating a collision event from detection of a busy medium. In various embodiments, the techniques discussed herein may be applied in PLC mesh networks with random medium access, although other types of networks may also be used. Furthermore, these embodiments may be used with various PLC standards, such as, for example, the G3-PLC standard or the like.

Turning now to FIG. **6**, a flowchart of a CSMA method is depicted according to some embodiments. In various embodiments, the method of FIG. **6** may be performed, for example, by PLC device **103**, PLC gateway **112**, and/or PLC data concentrator **114**. At block **601**, the method may include setting one or more backoff parameters (e.g., an NB counter and/or BE) to their initial values. At block **602**, the method may perform a VCS operation, for example, until the VCS operation determines that a communication channel is idle or free. Then, at blocks **602** and **603**, the method may create a delay and request that a PCS operation be performed similarly as in blocks **501** and **502** of FIG. **5**. In contrast with the method of FIG. **5**, however, in this case PCS is tried when VCS (virtual carrier sensing) is not busy. That is, VCS is consulted before PCS. When VCS becomes idle from a busy state, all the nodes (i.e., PLC devices) may be aligned at the same time for a fair competition for the channel. As such, both VCS and PCS may be used, and VCS saves the unnecessary PCS so that CSMA does not fail, for example, due to large packet transmission.

At block **605**, the method may determine whether the channel is idle or free based on the PCS operation. If so, the method may send data over the channel at block **606**. At block **607**, the method may determine whether the data transmission is a broadcast or a unicast transmission (the latter involves receiving an acknowledgement message in response to a successful transmission, whereas the former does not). If the data transmission is a unicast transmission,

the method may determine whether an acknowledgement has been received at block **608**. If the data transmission is a broadcast transmission or if an acknowledgement has been received for a unicast transmission, the method may end with a success indication. Otherwise, at block **609**, both NB and BE may be incremented.

Returning to block **605**, if the channel is busy, only NB may be incremented (but not the size of the contention window). Then, at block **611**, if the maximum number of backoffs has been reached, the method may end with a failure indication. Otherwise the method may return to block **602**. As such, BE may be increased if an acknowledgment (ACK) message or packet is not received (in the case of a unicast transmission). When PCS returns idle, a data frame may be sent out. Otherwise, the method may wait for the VCS to finish and BE remains the same value. When data is sent out without an ACK message being received, BE is increased. After a busy indication from the PCS operation, however, the node or device may not increase its contention window so that all the nodes can have a fair CSMA competition. That is, only after an ACK is lost, thus suggesting a possible packet collision and crowded medium, may the node increase the contention window to compete with other devices for use of the channel.

It should be noted that, when an ACK is lost, potentially there are two most likely reasons. First, channel condition may be bad, in which case the sender may try to transmit again without increasing the contention window size. Second, there may have occurred a packet collision (due to the channel being busy), in which case competing senders may increase their time or contention window size before trying to transmit again. In some implementations, a sender and a receiver may interact with each other regarding the (past) lost ACK using extra bits in NACK (if NACK is able to be sent) or some additional exchange of information. The receiver may use the information to help the sender(s) differentiate the bad channel condition from the packet collision, so that the sender may respond differently when an ACK is lost. Additionally or alternatively, a receiver may also warn a sender about the bad channel using extra bits in the ACK packet if the receiver found the received packet has a low link quality indicator (LQI).

FIG. **7** is a block diagram of an integrated circuit according to some embodiments. In some cases, one or more of the devices and/or apparatuses shown in FIGS. **2-4** may be implemented as shown in FIG. **7**. In some embodiments, integrated circuit **702** may be a digital signal processor (DSP), an application specific integrated circuit (ASIC), a system-on-chip (SoC) circuit, a field-programmable gate array (FPGA), a microprocessor, a microcontroller, or the like. Integrated circuit **702** is coupled to one or more peripherals **704** and external memory **703**. In some cases, external memory **703** may be used to store and/or maintain databases **304** and/or **404** shown in FIGS. **3** and **4**. Further, integrated circuit **702** may include a driver for communicating signals to external memory **703** and another driver for communicating signals to peripherals **704**. Power supply **701** is also provided which supplies the supply voltages to integrated circuit **702** as well as one or more supply voltages to memory **703** and/or peripherals **704**. In some embodiments, more than one instance of integrated circuit **702** may be included (and more than one external memory **703** may be included as well).

Peripherals **704** may include any desired circuitry, depending on the type of PLC system. For example, in an embodiment, peripherals **704** may implement local communication interface **303** and include devices for various types

of wireless communication, such as WI-FI, ZIGBEE, BLUETOOTH, cellular, global positioning system, etc. Peripherals **704** may also include additional storage, including RAM storage, solid-state storage, or disk storage. In some cases, peripherals **704** may include user interface devices such as a display screen, including touch display screens or multi-touch display screens, keyboard or other input devices, microphones, speakers, etc.

External memory **703** may include any type of memory. For example, external memory **703** may include SRAM, nonvolatile RAM (NVRAM, such as “flash” memory), and/or dynamic RAM (DRAM) such as synchronous DRAM (SDRAM), double data rate (DDR, DDR2, DDR3, etc.) SDRAM, DRAM, etc. External memory **703** may include one or more memory modules to which the memory devices are mounted, such as single inline memory modules (SIMMs), dual inline memory modules (DIMMs), etc.

It will be understood that various operations illustrated in FIG. **6** may be executed simultaneously and/or sequentially. It will be further understood that each operation may be performed in any order and may be performed once or repetitiously. In various embodiments, the modules shown in FIGS. **2-4** may represent sets of software routines, logic functions, and/or data structures that are configured to perform specified operations. Although these modules are shown as distinct logical blocks, in other embodiments at least some of the operations performed by these modules may be combined in to fewer blocks. Conversely, any given one of the modules shown in FIGS. **2-4** may be implemented such that its operations are divided among two or more logical blocks. Moreover, although shown with a particular configuration, in other embodiments these various modules may be rearranged in other suitable ways.

Many of the operations described herein may be implemented in hardware, software, and/or firmware, and/or any combination thereof. When implemented in software, code segments perform the necessary tasks or operations. The program or code segments may be stored in a processor-readable, computer-readable, or machine-readable medium. The processor-readable, computer-readable, or machine-readable medium may include any device or medium that can store or transfer information. Examples of such a processor-readable medium include an electronic circuit, a semiconductor memory device, a flash memory, a ROM, an erasable ROM (EROM), a floppy diskette, a compact disk, an optical disk, a hard disk, a fiber optic medium, etc.

Software code segments may be stored in any volatile or non-volatile storage device, such as a hard drive, flash memory, solid state memory, optical disk, CD, DVD, computer program product, or other memory device, that provides tangible computer-readable or machine-readable storage for a processor or a middleware container service. In other embodiments, the memory may be a virtualization of several physical storage devices, wherein the physical storage devices are of the same or different kinds. The code segments may be downloaded or transferred from storage to a processor or container via an internal bus, another computer network, such as the Internet or an intranet, or via other wired or wireless networks.

Many modifications and other embodiments of the invention(s) will come to mind to one skilled in the art to which the invention(s) pertain having the benefit of the teachings presented in the foregoing descriptions, and the associated drawings. Therefore, it is to be understood that the invention(s) are not to be limited to the specific embodiments disclosed. Although specific terms are employed

herein, they are used in a generic and descriptive sense only and not for purposes of limitation.

The invention claimed is:

1. A method comprising:
 - periodically determining, by a communication device, whether a communication channel is idle or busy;
 - determining a first backoff time for a first transmission attempt based on a second backoff time for a second transmission attempt by adjusting, by the communication device, the second backoff time based on detecting a first collision event involving the second transmission attempt while the communication channel is determined idle;
 - determining a third backoff time for a third transmission attempt based on a fourth backoff time for a fourth transmission attempt by refraining, by the communication device, from adjusting the fourth backoff time based on a determination that the communication channel is busy during the fourth transmission attempt;
 - determining a fifth backoff time for a fifth transmission attempt based on a sixth backoff time for a sixth transmission attempt by refraining, by the communication device, from adjusting the sixth backoff time based on absence of a second collision event involving the sixth transmission attempt; and
 - suspending, by the communication device, each of the first, second, third, fourth, fifth, and sixth transmission attempts during a respective one of the first, second, third, fourth, fifth, and sixth backoff times.
2. The method of claim 1, wherein the periodically determining whether the communication channel is idle or busy includes:
 - performing, by a media access control (MAC) layer of the communication device, a virtual carrier sense (VCS) operation to determine an expected occupancy of the communication channel.
3. The method of claim 2, wherein the periodically determining whether the communication channel is idle or busy includes:
 - performing, by a physical layer of the communication device, a physical carrier sense (PCS) operation after the expected occupancy expires to determine whether the communication channel is idle or busy.
4. The method of claim 3, wherein the suspending of the first transmission attempt includes suspending access to the communication channel during the first backoff time after the VCS operation and before the PCS operation.
5. The method of claim 1, wherein the detecting of the first collision event includes:
 - transmitting, by the communication device, a unicast package to the communication channel; and
 - detecting, by the communication device, the first collision event when an acknowledge message is not received from the communication channel within a predetermined time period after the unicast package is transmitted.
6. The method of claim 1, wherein the adjusting of the second backoff time includes increasing a backoff exponent related to a contention window.
7. The method of claim 1, wherein the refraining from adjusting the fourth backoff time includes maintaining unchanged a backoff exponent related to a contention window.

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8. The method of claim 1, further comprising:
 incrementing, by the communication device, a backoff
 counter upon determining the communication channel
 is busy or detecting the first collision event;
 repeating, by the communication device, a transmission
 attempt when the backoff counter is less than or equal
 to a predetermined threshold; and
 terminating, by the communication device, the transmis-
 sion attempt when the backoff counter exceeds the
 predetermined threshold.
9. The method of claim 1, wherein:
 the communication channel includes a frequency band
 conducted by a power line; and
 the communication device includes a power line commu-
 nication (PLC) device coupled with a data concentrator
 via the communication channel.
10. A power line communication (PLC) device compris-
 ing:
 a gateway engine configured to access a communication
 network via a communication channel conducted by a
 power line; and
 a memory coupled to the gateway engine and storing
 instructions that, upon implemented by the gateway
 engine, cause the gateway engine to:
 periodically determine whether the communication
 channel is idle or busy;
 determine a first backoff time for a first transmission
 attempt based on a second backoff time for a second
 transmission attempt by:
 adjusting the second backoff time based on detecting
 a first collision event while the communication
 channel is determined idle;
 refraining from adjusting the second backoff time
 based on the communication channel being deter-
 mined busy; and
 refraining from adjusting the second backoff time
 based on absence of a second collision event; and
 suspend the first transmission attempt during the first
 backoff time.
11. The PLC device of claim 10, wherein:
 the gateway engine includes a media access control
 (MAC) layer configured to periodically determine
 whether the communication channel is idle or busy by
 performing a virtual carrier sense (VCS) operation to
 determine an expected occupancy of the communica-
 tion channel.
12. The PLC device of claim 11, wherein:
 the gateway engine includes a physical layer configured to
 periodically determine whether the communication
 channel is idle or busy by performing a physical carrier
 sense (PCS) operation after the expected occupancy
 expires to determine whether the communication chan-
 nel is idle or busy.
13. The PLC device of claim 12, wherein the gateway
 engine is configured to suspend the first transmission
 attempt by suspending access to the communication channel
 during the first backoff time after the VCS operation and
 before the PCS operation.

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14. The PLC device of claim 10, wherein the gateway
 engine is configured to detect the first collision event by:
 transmitting a unicast package to the communication
 channel; and
 detecting the first collision event based on an acknowl-
 edge message not being received from the communi-
 cation channel within a predetermined time period after
 the unicast package is transmitted.
15. The PLC device of claim 10, wherein the gateway
 engine is configured to adjust the second backoff time by
 increasing a backoff exponent related to a contention win-
 dow.
16. The PLC device of claim 10, wherein the gateway
 engine is configured to refrain from adjusting the second
 backoff time by maintaining unchanged a backoff exponent
 related to a contention window.
17. The PLC device of claim 10, wherein the gateway
 engine is configured to:
 increment a backoff counter based on determining the
 communication channel is busy or detecting the first
 collision event;
 perform the first transmission attempt based on the back-
 off counter being less than or equal to a predetermined
 threshold; and
 terminate the first transmission attempt based on the
 backoff counter exceeding the predetermined thresh-
 old.
18. The PLC device of claim 10, further comprising:
 a database coupled with the gateway engine, the database
 configured to store frequency data related to the com-
 munication channel;
 wherein the gateway engine is configured to manage the
 communication channel based on the stored frequency
 data.
19. A nontransitory computer readable medium storing
 instructions that, upon implemented by a gateway engine of
 a power line communication (PLC) device, cause the gate-
 way engine to perform a method comprising:
 periodically determining whether a communication chan-
 nel is idle or busy;
 determining a first backoff time for a first transmission
 attempt based on a second backoff time for a second
 transmission attempt that is prior to the first transmis-
 sion attempt by:
 adjusting the second backoff time based on detecting a
 first collision event while the communication chan-
 nel is determined idle;
 refraining from adjusting the second backoff time based
 on a determination that the communication channel
 is busy; and
 refraining from adjusting the second backoff time based
 on receiving an acknowledgment that indicates
 absence of a second collision event; and
 suspending the first transmission attempt during the first
 backoff time.
20. The nontransitory computer readable medium of
 claim 19, wherein periodically determining whether the
 communication channel is idle or busy includes:
 directing a media access control (MAC) layer of the
 gateway engine to perform a virtual carrier sense
 (VCS) operation to determine an expected occupancy
 of the communication channel.